

The Effects of Water Deficit and Particle Film Technology Interactions on Cabernet Sauvignon Grape Composition

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Abstract

Regulated deficit irrigation (RDI) has been shown to increase water use efficiency and improve wine quality. In Australia, RDI is commonly practiced in irrigated regions with warm climates and low rainfall, often where periods of heat stress may occur during the deficit irrigation period. The aim of this study was to assess the effect of particle film technology (PFT) for lowering the leaf temperature relative to ambient temperature, resulting in cooler leaves during the period of deficit irrigation and to assess its effects on Cabernet Sauvignon grape composition at harvest. Experiments were conducted in a commercial vineyard in the Sunraysia region (Australia) over two seasons, 2004 and 2005. Three irrigation treatments were imposed, an RDI and a prolonged deficit treatment (PD) which were compared to an industry standard drip irrigation practice. PFT was applied shortly after the initiation of RDI. PFT treatments were imposed onto the irrigation treatments and were described as non-PFT (i.e. no PFT, effect of irrigation) and plus-PFT (effect of PFT). Plus-PFT treatments resulted in lower canopy temperatures (season 2004). No significant interaction with deficit irrigation and PFT application was found. Plus-PFT treatments did not impact on yield, berry weight or pH of berry juice at harvest. Plus-PFT increased berry juice organic acid concentrations, tartaric, malic and citric acid along with increases to sucrose and glucose concentrations. Effects on anthocyanin and phenolic concentrations were more sensitive to seasonal impacts than to plus-PFT. Interestingly, the mean January temperatures for the respective seasons were average (in 2004) or up to 1°C below the 58-year average (in 2005). Implementing deficit irrigation and PFT strategies can have impacts on berry quality indicators and may be more significant in seasons where January temperatures are above average.

INTRODUCTION

Water deficits are regularly applied to grapevines within Australia as a management tool, primarily to reduce canopy vigour, and often result in indirect changes to winegrape composition (Kriedemann and Goodwin, 2003). Irrigated regions where water deficits are routinely applied, such as the Riverland or Sunraysia, are often associated with warm climates. For example, degree days after flowering for seasons 2005 and 2004 in Sunraysia were respectively 1494 and 1760°C d⁻¹ (applying a 10°C base). Applying water deficits on hot days, with high vapour pressure deficit can result in large reductions in stomatal conductance (Gs), which in turn can reduce transpiration (T) and carbon assimilation (A) (Cooley, 2004). Where A is significantly reduced over extended periods, changes to the amount of carbon available for storage (root growth, storage and/or berry sugar accumulation) may occur (Bota et al., 2001; Boland et al.,

2000 a, b). Reductions to carbon available for storage could have large impacts on vine season to season performance (Cooley et al., 2006).

Reducing leaf and canopy temperature while applying a deficit, could reduce the negative impacts on Gs, T and A, which therefore may address the issues of sustainability. Particle Film Technology (PFT), a kaolin particle film applied to the canopy, is one method which could be used to reduce canopy temperature (Glenn et al., 2001). PFT, which appears white when applied, has been shown in some crops to increase Gs (Glenn et al., 2006; Jifon and Syvertsen, 2003), T (Glenn et al., 2006) and A (Glenn et al., 2001, 2006; Jifon and Syvertsen, 2003).

The aim of this study was to assess the effect of particle film technology (PFT) for lowering the leaf temperature relative to ambient temperature, resulting in cooler leaves during the period of deficit irrigation and to assess its effects on Cabernet Sauvignon grape composition at harvest.

MATERIALS AND METHODS

Experiments were conducted over two seasons, 2004 and 2005 on a commercial vineyard (Wingara Wine group) in the Sunraysia region of Victoria, Australia (34°25' S, 142°21' E). Cabernet Sauvignon (*Vitis vinifera* L.) on its own roots was planted in 1995 in a Nookamka sandy loam (Penman et al. 1939). The row by vine spacing was 3 m by 2.4 m and vines were trained to a two wire vertical trellis with wires at 1.5 and 1.8 m. Vines retained approximately 150 buds in a mechanically hedged system. Irrigation was supplied via drippers, delivering 4 L/h and spaced at 0.6 m. Deficit irrigation treatments were applied by monitoring soil moisture (bi-weekly each morning by neutron probes, 50% of full point) in all treatments and by visual assessment of canopy area to crop load. Particle film technology was applied to three irrigation treatments: (1) a standard drip irrigation treatment which was maintained at close to field capacity during the deficit periods; (2) a regulated deficit irrigation (RDI) treatment which received industry standard irrigation until the end of flowering, then at fruit set the water applied was halved by reducing irrigation duration and maintained at the reduced level until reduced shoot length was obtained (two/three weeks), and (3) a prolonged deficit treatment (PD) which received the same amount of water applied as the RDI treatment followed by a period of no irrigation between the end of the RDI period and the beginning of veraison (change of grape colour from green to red).

The three irrigation treatments were randomly situated. Each irrigation treatment consisted of 12 replicate blocks. Within each replicate block, samples were collected from 1 of 3 vines with no PFT treatment (non-PFT) and 1 of 2 vines with PFT treatment (plus-PFT). Each replicate block comprised both buffer vines and buffer rows. PFT at 3% was applied over 4 applications (Surround WP, Engelhard Corp. Iselin, NJ, USA). During season 2005 the irrigation treatments non-PFT were the same as 2004 whereas the plus PFT (at 3%, two applications were required to establish film) were located on buffer rows. The same number of plots were used with each season. Particle film technology (PFT) is based on kaolin, which is a white, non-porous, non-swelling, low-abrasive, plate-shaped, aluminosilicate mineral ($\text{Al}_4\text{Si}_4\text{O}_{10}(\text{OH})_8$) with a brightness of >85%. The kaolin easily disperses in water and is chemically inert over a wide pH range (Glenn and Puterka, 2005). The first 2 applications established a particle film, and later applications re-established the particle film after rainfall.

Canopy temperature was measured with infrared temperature transducers (Model IRTS, Apogee Instruments Inc. Logan, UT, USA) located 30 cm above the canopy at a 30 degree angle from horizontal in a single replicate of the study area. Canopy temperature was recorded for six replicates. A non-aspired, shaded thermocouple was attached to each infrared temperature transducer. The infrared temperature transducers were oriented in a northerly direction parallel with the canopy row to prevent shading of the canopy. Data were collected by a datalogger (Model CR7, Campbell Scientific, Logan, UT, USA) located in each replicate. The dataloggers had intermittent data loss, therefore only dates (n=28) in which data are available for all 3 replicates were analyzed and presented. Air

temperature for the study site was the mean of 6 sensors above canopy.

Harvest date was determined by an optimal total soluble solid reading of 24.5° Brix. Five bunches per vine were randomly collected as described by Krstic et al. (2003). Bunches were placed in plastic bags and stored on ice during transfer from the field to the laboratory. The total fresh weight of 100 randomly selected berries per plot was recorded and juice samples were extracted by pressing (pestle and mortar) into a pulp and then filtering the sample through a 1 mm² mesh. Total soluble solids (temperature compensating digital refractometer, Atago, Tokyo, Japan), pH and titratable acidity (5 ml sample with acid equivalents titrated to an end point of pH 8.2 using an auto-titrator SAC 80 Sample Changer, ABU91 Autoburette and VIT90 Video titrator, Radiometer-Copenhagen, Linsellesstr, Germany) were determined. Berry juice organic acids and soluble carbohydrates were determined (see below for HPLC details). A second subsample consisting of 100 randomly selected berries per plot was placed in a self-seal plastic bag and immediately placed at -18°C for storage until pigment analysis could be conducted. Total anthocyanin (colour) and total phenolic concentration in fruit (whole berries) was measured by the UV-vis spectrophotometric method developed by Somers and Evans (1977) and modified by Iland (1996). Calculations of degraded index (DI), an indicator of colour quality, were based on work by Fuleki and Francis (1968). $DI = [\text{total anthocyanin}] / [\text{non-degraded anthocyanin}]$. The detection and quantification of sugars and organic acids in the berry juice sample was based on the work by Toulouee and Fares (2005). The HPLC system (GBC Scientific Equipment Pty Ltd, Dandenong, Victoria, Australia) consisted of an LC1610 auto-sampler, LC1150 pump with in-line degasser, LC1210 UV/UV-vis detector, reflective index (RI) detector and operated via the WinChrom chromatography manager software. A 'Rezex' organic acid column (Phenomenex Inc., Torrance, CA, USA, part No.OOH-1038-KO) protected by the 'Security Guard' (Phenomenex Inc.) was operated at 79°C. The mobile phase was 0.005 M sulphuric acid at a flow rate of 0.6 ml per min (total run time 35 min). Two detectors were employed; the UV-vis detected the standards citric, tartaric and lactic acid at 210 nm, whereas the reflective RI identified the organic acids standards, citric, tartaric, malic, succinic, acetic and lactic acids along with the sugars glucose, fructose, sucrose and sorbitol. The sample injection volume was 20 µl and concentration was determined using peak area.

Mean values were calculated and treatment differences were tested by two-way analysis of variance using GenStat 6th Edition (VSN International Limited, Oxford, UK). The main effects were irrigation treatment by PFT and the blocking was defined by columns. Where significant differences were found, mean values were separated using Fisher's least significant difference (LSD) test ($P = 0.05$).

RESULTS AND DISCUSSION

The application of PFT (plus-PFT) significantly reduced canopy temperature compared to canopy temperature without PFT (non-PFT, irrigation effect) during the season 2004 period of berry development (Table 1). Measurements were not recorded during 2005.

Berry composition at harvest was measured for both seasons. The effect of RDI and PD have been reported previously (Cooley et al., 2004, 2006), resulting in reduced berry size. No significant effect of irrigation was found during season 2004 or 2005 on anthocyanin or phenolic concentration.

There was no irrigation by PFT interaction on any parameter measured here in either season. This suggests that while deficit irrigation and PFT both exerted effects on berry composition, these effects were independent of each other. This has interesting consequences when managing a crop for quality and canopy temperature. The need for water conservation in some vineyards has resulted in long and significant water deficit. When deficit irrigation reduces canopy size a higher temperature can occur and PFT application can be used to ameliorate this. While PFT reduces canopy temperature its impacts on water use efficiency (WUE) are complicated and will depend on the degree of

the deficit (Glenn et al., 2007).

Plus-PFT treatment did not significantly impact fresh, dry berry weight or yield compared to the non-PFT treatment during both seasons (Table 2). The effect of PFT on TSS was different in both seasons, suggesting that other factors exerted a greater effect on TSS, other than relative canopy temperature differences (Table 3). Plus-PFT had no effect on TSS per berry during either season (Table 3). Significant increases in both glucose and fructose concentrations were observed during both seasons (Table 3) with plus-PFT treatment but no significant increase with irrigation treatments. The increases in the hexose concentration (glucose and fructose) with PFT application suggested that as the leaf photosynthetic rate increased (Glenn et al., 2007) more sugar was being translocated into the berry. The contribution of fructose concentration to TSS in the non-PFT treatment was consistent during both seasons (39-40%) and was higher than the contribution of glucose (33% in 2005 and 36% in 2004) in both seasons. These observations are reflected in changes to the glucose fructose ratio (Table 3).

Although the contribution of total organic acids to TSS was smaller than that of the sugars, it is nonetheless a significant component (organic acid contributes 0.6°Brix to TSS equivalent to 2.7%). Organic acid concentration measured indirectly by titratable acidity, resulted in no significant effect with the plus-PFT during season 2005 but was significantly increased during season 2004 (Table 3). Conversely, berry juice pH at harvest was not affected by PFT application in both seasons. Where total organic acids were calculated by adding the concentration of the compounds; tartaric, malic, succinic and citric acid, a significant enhancement in the organic acid concentration with PFT was observed at harvest in both seasons (Table 3). The organic acid constituents, in most cases, followed a similar trend during both seasons. PFT resulted in increases in tartaric, malic and citric acid concentration during season 2005 and 2004 (Table 3). Succinic acid concentration responded differently with seasons, showing a significant increase in concentration in season 2005 with plus-PFT compared to non-PFT, but no significant effect during season 2004 (Table 3). Citric acid was found in much lower concentrations than the other organic acids measured. Plus-PFT treatment did not significantly effect sugar acid ratio during season 2005 but during season 2004 a significant decrease in the ratio was found compared to non-PFT treatment.

The response of plus-PFT treatment was different with whole berry phenolic and anthocyanin concentrations during each season (Table 2). The PFT treatment significantly reduced anthocyanin concentration compared to the non-PFT treatment during season 2005 but had no significant effect on anthocyanin per berry. During season 2004, PFT treatment had no significant effect on anthocyanin concentration or anthocyanin content (Table 2). Phenolic concentration in season 2005 was significantly reduced compared to the non-PFT treatment (Table 2). In contrast, plus-PFT significantly increased phenolic concentration compared to the non-PFT treatment in season 2004 (Table 2). A change in the light environment (Downey et al., 2004) has been shown to reduce synthesis of flavonol in Shiraz grape berry skin but had no effect on anthocyanin accumulation. Phenolic content (phenolics per berry) was not effected by plus-PFT during season 2005 but was significantly increased compared to non-PFT treatment in 2004 (Table 2). Applying a water deficit alters the relationship between crop load and canopy vegetation. Application of PFT can result in changes to light quality (Glenn et al., 2002). Light changes coupled with temperature reductions and a water deficit is a complicated combination and probably contributed to the seasonal variations to anthocyanin and phenolic concentrations. Separating the cause and effect of light interaction with temperature is technically challenging. Degradation index, which is an indication of berry colour quality, was significantly increased during both seasons suggesting a reduction in desirable colour quality with plus-PFT, although the effect was numerically small.

The industry standard irrigation practice supplied less than field capacity (based on soil moisture data) throughout most of the season. Therefore the standard treatment during berry development and at harvest may have been subjected to water stress. A combination of water stress and environmental factors may account for the lack of

interaction with the PFT application and deficit irrigation. The mode of action of PFT is different to the mode of action of a water deficit. PFT application reduces relative leaf temperature by altering the light environment enabling high rates of water use during warm days, while the water deficit is reducing canopy size which reduces the crop water requirement. The different modes of action may also explain the lack of significant interaction between the PFT and the water deficit.

Application of PFT reduced canopy temperature. Reduction to canopy temperature did not result in a deficit irrigation and PFT interaction on berry composition. The effect of PFT application is independent of deficit irrigation treatments and is complicated as a balance between canopy temperature, the light environment and water movement through the plant (evaporative transpiration and stomatal conductance relationships) can all impact on berry composition.

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Tables

Table 1. Cabernet Sauvignon canopy temperature at significant developmental stages with particle film technology (plus-PFT) and without (non-PFT) during season 2004. Mean \pm standard error values are shown.

Day of Year	Development stage	Ambient temperature (°C)	Canopy temperature (°C)		P-value
			non-PFT	plus-PFT	
13	pre véraison	34.8	32.0 \pm 1.1	29.7 \pm 1.2	< 0.05
19	50% véraison	31.2	24.8 \pm 1.0	22.2 \pm 1.0	< 0.05
50	post véraison	36.0	22.9 \pm 0.5	19.6 \pm 0.2	< 0.05
72	harvest	22.5	19.6 \pm 0.5	18.2 \pm 0.4	< 0.05

Table 2. Cabernet Sauvignon whole berry analysis at harvest with particle film technology (plus-PFT) and without (non-PFT) during seasons 2004 (day of the year 74) and 2005 (day of the year 61). Mean \pm standard error values are shown. Not significant = n.s.

Whole berry analysis	Season 2004			Season 2005		
	non-PFT	plus-PFT	P-value	non-PFT	plus-PFT	P-value
Berry fresh weight (g)	0.80 ± 0.01	0.8 ± 0.01	n.s	0.85 ± 0.02	0.89 ± 0.01	n.s
Berry dry weight (g)	0.15 ± 0.004	0.16 ± 0.002	n.s	0.23 ± 0.01	0.22 ± 0.01	n.s
Anthocyanin (mg g ⁻¹)	1.9 ± 0.05	1.9 ± 0.05	n.s	1.8 ± 0.06	1.5 ± 0.05	0.005
Anthocyanin per berry (mg)	1.5 ± 0.05	1.5 ± 0.01	n.s	1.5 ± 0.05	1.4 ± 0.05	n.s
Phenolic (mg g ⁻¹)	1.9 ± 0.04	2.1 ± 0.04	0.007	1.4 ± 0.05	1.3 ± 0.02	0.035
Phenolics per berry (mg)	1.5 ± 0.03	1.7 ± 0.06	0.003	1.2 ± 0.04	1.2 ± 0.03	n.s
Degradation Index	1.14 ± 0.01	1.15 ± 0.01	0.01	1.02 ± 0.01	1.09 ± 0.01	<.001
Yield (t ha ⁻¹)	20.4 ± 1.0	19.7 ± 0.7	n.s	28.5 ± 1.1	26.7 ± 1.2	n.s

Table 3. Cabernet Sauvignon berry juice analysis at harvest with particle film technology (plus-PFT) and without (non-PFT) during seasons 2004 (day of the year 74) and 2005 (day of the year 61). Mean \pm standard errors values are shown. Not significant = n.s.

Berry juice	Season 2004			Season 2005		
	non-PFT	plus-PFT	<i>P</i> -value	non-PFT	plus-PFT	<i>P</i> -value
Total soluble solids ($^{\circ}$ Brix)	24.2 ± 0.1	23.8 ± 0.1	0.014	24.6 ± 0.2	24.7 ± 0.2	n.s
Total soluble solids per berry (g)	0.19 ± 0.03	0.19 ± 0.03	n.s	0.20 ± 0.07	0.22 ± 0.06	n.s
Fructose (g L ⁻¹)	96 ± 2	123 ± 3	<.001	97 ± 3	127 ± 2	<.001
Glucose (g L ⁻¹)	87 ± 2	93 ± 2	<.001	80 ± 3	101 ± 2	<.001
Glucose fructose ratio	0.90 ± 0.008	0.76 ± 0.002	<.001	0.83 ± 0.005	0.79 ± 0.001	<.001
Acidity (g L ⁻¹)	5.0 ± 0.1	5.2 ± 0.1	0.025	5.3 ± 0.1	5.1 ± 0.1	n.s
pH	3.5 ± 0.01	3.5 ± 0.1	n.s	3.6 ± 0.01	3.6 ± 0.1	n.s
Total organic acid (g L ⁻¹)	6.9 ± 0.2	10.2 ± 0.4	<.001	5.9 ± 0.2	7.4 ± 0.2	<.001
Tartaric acid (g L ⁻¹)	5.8 ± 0.2	7.4 ± 0.3	<.001	5.0 ± 0.5	5.7 ± 0.2	<.001
Malic acid (g L ⁻¹)	0.87 ± 0.05	3.29 ± 0.30	<.001	0.76 ± 0.05	1.47 ± 0.06	<.001
Succinic acid (g L ⁻¹)	3.4 ± 0.1	3.0 ± 0.1	n.s	1.6 ± 0.1	3.4 ± 0.1	<.001
Citric acid (g L ⁻¹)	0.23 ± 0.01	0.18 ± 0.01	0.025	0.10 ± 0.01	0.19 ± 0.01	0.025
Tartaric malic ratio	7.1 ± 0.3	3.5 ± 0.5	<.001	7.9 ± 0.1	4.0 ± 0.2	0.002
Sugar acid ratio	48.9 ± 0.8	46.1 ± 0.8	0.004	47.1 ± 0.8	48.7 ± 1.0	n.s